



Dredging Research Technical Notes



Numerical Disposal Modeling Needs Revealed by Mobile Bay Field Data

Purpose

Field data collected at a disposal site in Mobile Bay during 1989 have been used to illustrate deficiencies in an existing numerical disposal model called SSTFATE (Single Operation - Short Term FATE). These data were collected using acoustic devices and reveal the dynamics of the disposal operation as well as the passive nature of resulting suspended sediment plumes. An application of the numerical model to one of the 18 monitored disposal operations demonstrates the need to allow for the nonuniformity of material in the disposal vessel.

Background

An integral part of the problem of assessing the environmental impact of disposal operations is the ability to predict the spatial and temporal distribution of the disposed material. Numerical models for computing the initial fate of material disposed in open waters have been developed for this purpose. One such model is SSTFATE. The basic model was developed by Koh and Chang (1973), subsequently modified by Brandsma and Divoky (1976), and later modified by Johnson (1990). However, such disposal models suffer from a lack of field data from controlled operations for model verification.

Because of the many factors governing the physical fate of dredged material placed in open waters and the speed with which the placement processes take place, measurement of the short-term behavior of a dredged material disposal plume is extremely difficult. To improve on this limited measurement capability, as well as collect high-quality data on the dynamics of dredged material disposal for validation of numerical disposal models, Dredging Research Program (DRP) research work units conducted a major field data collection project in the Gulf of Mexico at the site of dredged material placement operations being carried out for Mobile Harbor deepening and improvement. This field effort, called the Mobile, Alabama, Field Data Collection Project (MFDCP), took place from August 13 to September 2, 1989.

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Additional Information

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Mobile Field Data Collection Project

The overall scope of the MFDCP was greater than only measurement of the short-term dynamics of disposal operations and the tracking of the resultant suspended sediment plumes. However, for the purpose of this study, only those data related to the placement processes are of interest. A complete description of the MFDCP is given by Kraus (1991) from which much of the discussion below was taken.

The MFDCP took place in the Gulf of Mexico at a dredged material placement site west of the navigation channel leading to Mobile Harbor, Mobile, Alabama (Figure 1). Disposals were made at two fixed locations, one in water of nominal 13-m depth and the other in shallower water of about 8-m depth. Critical operational parameters for successful monitoring were knowledge of the exact location and time of disposal, rapid entry into the plume, and accurate tracking of the main plume body as it drifted with the current.

Plume tracking in the MFDCP centered around three instruments: the ADCP (Acoustic Doppler Current Profiler), the ACP (Acoustic Concentration Profiler), and a rosette containing twelve 5-L sampling bottles that could be activated electronically at a specified depth. The rosette, referred to as a CTD (for Conductivity, Temperature, and Depth), yielded samples of suspended material in the water prior to the disposal (background) and in the plume to calibrate the acoustic instruments and also provided salinity samples at various depths.

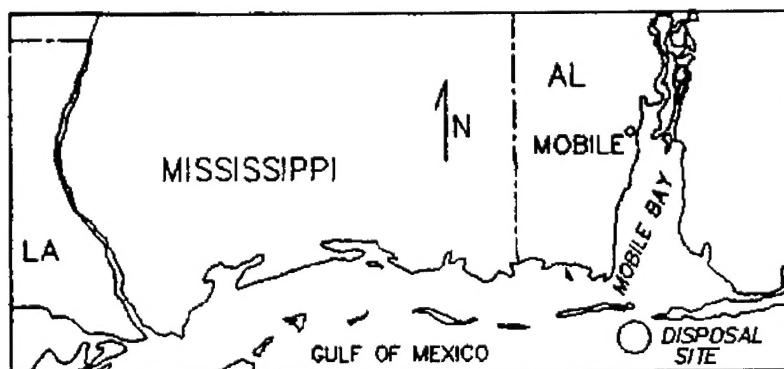


Figure 1. Location map

Two general tracking procedures were used to monitor the evolution of dredged material plumes through the water column. One is called transverse transect tracking and involves maneuvering of the monitoring vessel such that the plume is entered perpendicular to its major axis. After the width of the plume is passed, the survey ship turns around and attempts to reenter the plume at a right angle. In longitudinal transect tracking, the survey ship follows the dump scow and passes through the plume along its major axis, turning to reenter the plume only after its perimeter is exceeded. These procedures are continued until the plume can no longer be detected. The advantage of the transverse transect survey procedure is that time development of the vertical and lateral extent of a plume can be observed in a series of relatively rapid passes through the material. This enables, for example, the speed of the leading edge of the bottom surge to be recorded, as well as the descent of the main body of the plume to the bottom. The advantage of longitudinal tracking is that the entire body of the plume is surveyed at least once (on the first transect following the scow), giving full coverage of the length of the plume.

The plume-tracking procedure is not straightforward because a plume will be advected by existing currents. Wind shear at the water surface and horizontal currents in the water column can translate the plume and shear it into separate bodies at various depths. For this reason, visual observation of the plume surface may not indicate the location of the main body of material settling in the water column. Therefore, during MFDCP plume tracking the plume mass was monitored visually and by the ADCP and ACP. Because of the capability of the ADCP to display plume backscatter, current speed, and ship track, this instrument was often used to help track the plume. Over the 10-day monitoring period, 18 disposal operations were monitored.

Analysis of Data Collected During Survey 238B

Disposal 238B occurred at 21:55 Greenwich Mean Time at the 13-m site. The disposal scow approached with a speed and heading of 6 knots and 351 deg from north and the prerelease draft was 21 ft. The tug captain reported 5,600 cu yd, estimated as containing 70 percent sand and 30 percent fines. A mound of what appeared to be sand was located in the middle of the scow, with water at the fore and aft ends. The density of the material in the scow ranged from about 1.40 g/cu cm near the surface to 1.95 g/cu cm near the bottom. The release was relatively rapid, occurring over perhaps 10 to 20 sec.

The ambient density varied in essentially a linear fashion from 1.02 g/cu cm near the water surface to 1.03 g/cu cm near the bottom. The ambient current was virtually constant in magnitude over the upper 10 m of the water column with a speed of about 18 cm/sec, but the current direction changed from essentially a southerly direction over the upper 6 m of the water column to a southeastern direction over the bottom 7 m. The background suspended sediment concentration was determined from a bottled sample to be 4.4 mg/L with the median size being 12.3 μm .

The survey consisted of five transverse transects followed by three longitudinal transects. The plume was virtually undetectable during the longitudinal transects. The track of the scow and the first transect are shown in Figure 2. The remaining transverse transects were taken at approximately the same location, but were increased in lateral extent with each succeeding transect. Data from Survey 238B were analyzed from the perspective of temporal change of the plume seen as a whole. The plume was traversed several times after the initial disposal, and each transect (although taking 3 to 5 min) can be seen as representing the state of the plume at a given averaged elapsed time.

The contour plots shown in Figures 3 to 6 show that the material falls as a narrow downward jet at the outset and then evolves into an upside-down mushroom-shaped cloud. The material spreads out from the bottom cloud in elapsed time. Simultaneously, the concentration in the main jet is reduced, and the whole plume is advected with the horizontal current. The concentration contours were developed from acoustic backscattering contours. The actual values should be viewed with caution since much work remains to be done in calibrating acoustic devices to suspended sediment concentrations. Calibration curves developed from the MFDCP data were used here.

Based upon an analysis of the MFDCP data by Kraus (1991), the following general observations can be made:

- A bottom surge is created which contains a leading head.
- The effect of the bottom manifests itself upon the movement of the plume and becomes evident at about the 8-m depth horizon at the 13-m site. The effect of the bottom upon the dynamic plume behavior is manifested as a large change in the slope of the outer plume boundary.

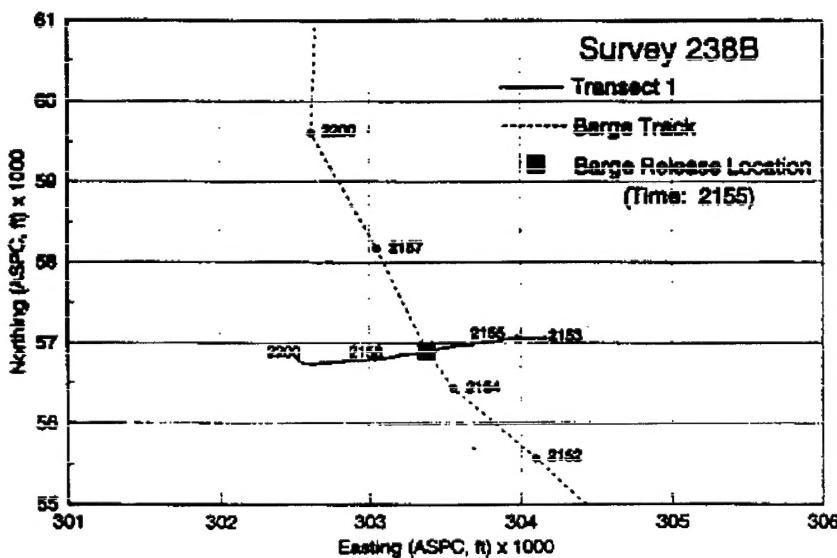


Figure 2. Survey 238B transect

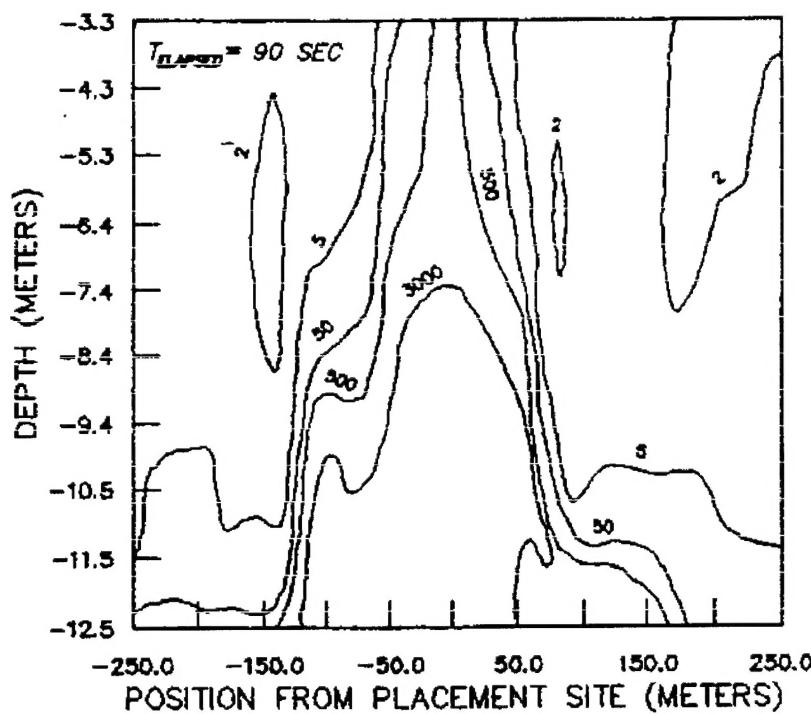


Figure 3. Cross-sectional contours in milligrams per liter of the disposal plume 90 sec after the disposal

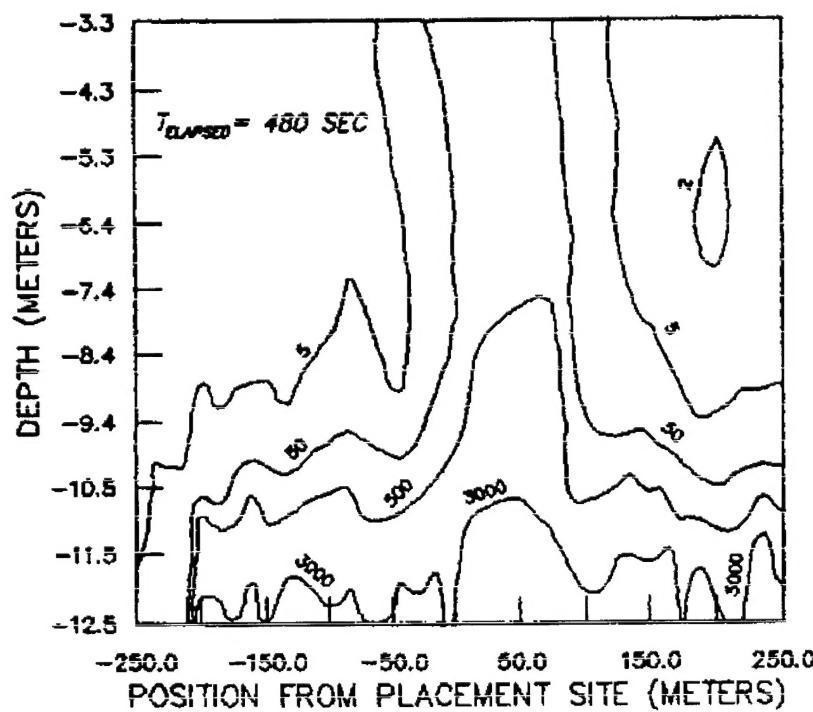


Figure 4. Cross-sectional contours in milligrams per liter of the disposal plume 480 sec after the disposal

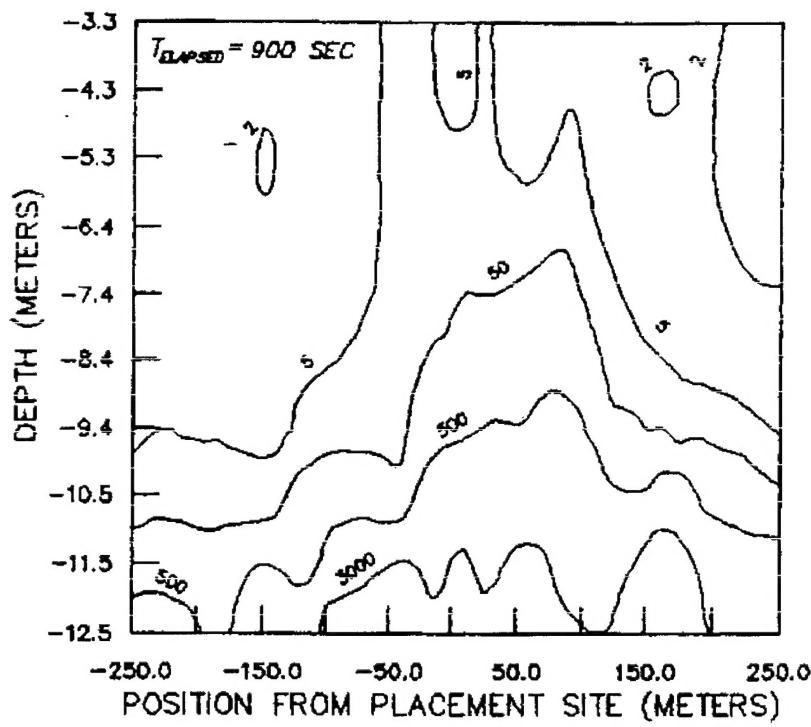


Figure 5. Cross-sectional contours in milligrams per liter of the disposal plume 900 sec after the disposal

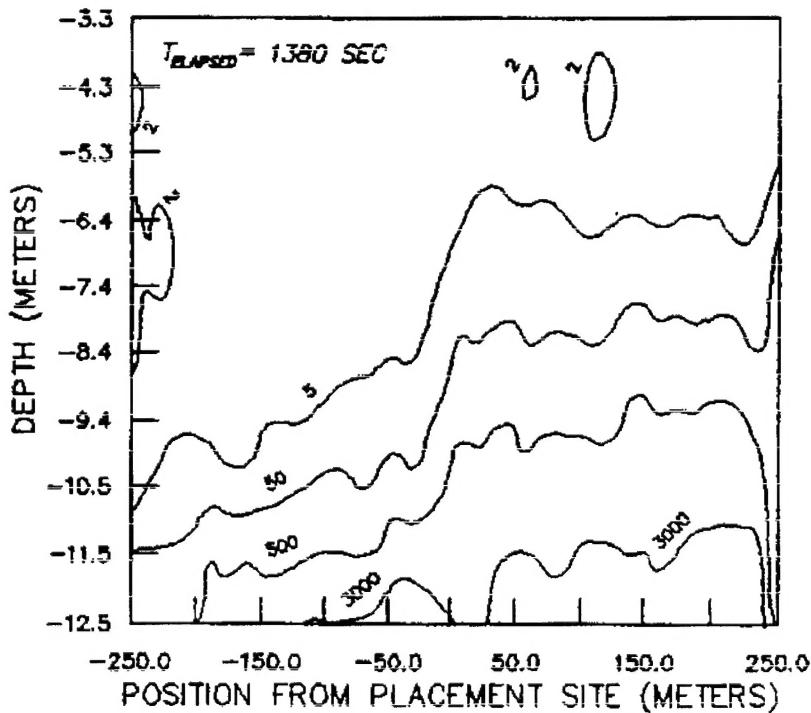


Figure 6. Cross-sectional contours in milligrams per liter of the disposal plume 1,380 sec after the disposal

- The nature of the disposal operation is such that the plume can separate into distinct lobes, settling at different rates.
- A strong current shear effect acts to horizontally separate the upper and lower water column portions of the plume.

Numerical Disposal Model Application Using Survey 238B Data

SSTFATE was applied to the disposal operation discussed in this note. All data required for operation of the model have been discussed earlier. These data include the disposal volume, concentration and settling rates of solid types, and ambient characteristics of the disposal site.

The behavior of the material is assumed to be separated into three phases: convective descent, during which the disposal cloud falls under the influence of gravity; dynamic collapse, occurring when the descending cloud either impacts the bottom or arrives at a level of neutral buoyancy where descent is retarded and horizontal spreading dominates; and passive transport-dispersion, beginning when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation. Each phase is discussed in the following paragraphs.

A single cloud that maintains a hemispherical shape during convective descent is assumed to be released. Since the solids concentration in discharged dredged material is usually low, the cloud is expected to behave as a dense liquid; a basic assumption is that a buoyant thermal analysis is appropriate. The equations governing the motion are those for conservation of mass, momentum, buoyancy, solid particles, and vorticity. The disposal material cloud grows during convective descent as a result of entrainment. Eventually, either the material reaches the bottom or the density difference between the discharged material and the ambient water column becomes small enough for a position of neutral buoyancy to be assumed. In either case, the vertical motion is arrested and a dynamic spreading in a horizontal plane occurs.

The basic shape assumed for the collapsing cloud is an oblate spheroid if collapse occurs in the water column; a general ellipsoid is assumed for collapse on a sloping bottom. With the exception of vorticity, which is assumed to have been dissipated by the stratified ambient water column, the same conservation equations used in convective descent but now written for either an oblate spheroid or an ellipsoid are applicable. For the case of collapse on the bottom, a frictional force between the bottom and the collapsing cloud is included which accounts for energy dissipation as a result of the radial spreading.

When the spreading rate in the dynamic collapse phase becomes less than an estimated spreading rate due to turbulent diffusion in both the horizontal

and vertical directions, the collapse phase is terminated. During collapse, solid particles can settle as a result of their fall velocity. As these particles leave the main body of material, they are stored in small clouds that are characterized by a Gaussian distribution. These clouds are then advected and diffused by the ambient current. In addition, settling of the suspended solids also occurs. Therefore, the amount of solid material deposited on the bottom and a corresponding thickness are determined. A basic assumption in the models is that once material is deposited on the bottom, it remains there; neither erosion nor bed-load movement of material is allowed. The time-dependent, three-dimensional field of suspended sediment concentrations is determined by summing the contribution from individual clouds.

Table 1 presents results from the numerical model. All of the sand is computed to have been deposited at the end of 90 sec, but only a small fraction of the fines have settled to the bottom. These results are based on assuming a settling velocity of 2.1 cm/sec for the sand and 0.05 cm/sec for the fines. If the fines had been considered cohesive, in which case the settling velocity is computed internally, the suspended sediment concentrations would have been quite different.

Table 1
Numerical Model Results

Time sec	Solid Type	Volume Deposited cu m	Maximum Concentration (mg/L)			Lateral Extent of Plume Near Bottom, m
			12 m	10.5 m	9 m	
90	Sand	1,198	0	0	0	--
90	Fines	15	104,000	23,660	2.1	230
480	Fines	57	96,000	14,400	6.5	275
900	Fines	96	18,720	7,280	2.9	410
1380	Fines	140	8,580	3,120	1.4	595

In addition to the settling velocity, vertical diffusion is a significant factor in suspended sediment computations. As evidenced by the extremely large concentrations computed near the bottom but with essentially background values only 3 to 4 m off the bottom, the stratification in the ambient density profile has resulted in virtually no vertical diffusion into the water column after collapse. At the end of the collapse phase, the cloud is on the bottom with a thickness of 1.3 m.

Comparison of Figures 3 through 6 with results presented in Table 1 shows that the numerical model does a good job of reproducing the extent of the bottom surge. However, because the entire disposal operation is represented as a single hemispherical cloud, water column effects are not reproduced well.

The field data clearly imply that the fine material is dispersed in the water column far more than the numerical results show. Uncertainty concerning the amount and character of the fine material contributes to this; however, a major reason that water column effects are not reproduced well is that the actual placement process is governed by a well-defined jet transporting material to the bottom with extremely fine material making up the trailing body of the jet. This extremely fine fraction is contained near the surface in the disposal vessel. Therefore, a variable density of material in the disposal vessel must be allowed for to reproduce water column effects. The separation of the disposal cloud between the upper and lower portions of the water column due to velocity shear and stratification as observed in some of the MFDCP data undoubtedly involves the extremely fine fraction that leaves the disposal vessel after the main body of material has descended through the water column.

References

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- Kraus, N. C., editor. 1991. "Mobile, Alabama, Field Data Collection Project, 18 August-2 September 1989; Report 1, Dredged Material Plume Survey Data Report," Technical Report DRP-91-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

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